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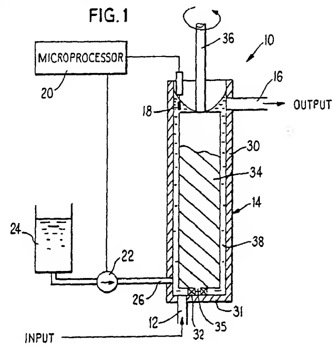
(54) pH controller

(57) A pH controller for a liquid stream includes a pump (22) to inject a pH-changing additive into the stream, a mixing chamber (38), an electrode (18) to measure the pH of the emerging liquid, and means to adjust operation of the pump in accordance with that measurement. The mixing chamber (38) is of annular form, defined between two concentric cylinders (30, 34) the inner one (34) of which is rotated. The rotation speed and the throughput can be adjusted to give very thorough mixing and hence to enable the pH to be held at a steady value. The flow regime appears to involve Taylor vortices (40) which together define a single helical path for the liquid. The liquid treated may comprise effluent form nuclear fuel reprocessing (e.g. containing nitric acid and ferric nitrate) to which is added NaOH solution to achieve a pH of 9-10.5, to precipitate ferric hydroxide floc.

FIG. 1



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy

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FIG. 1

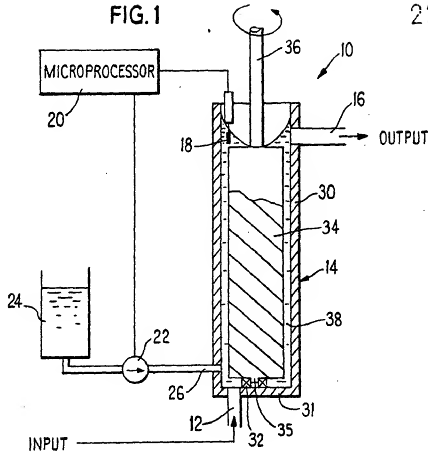


FIG. 2

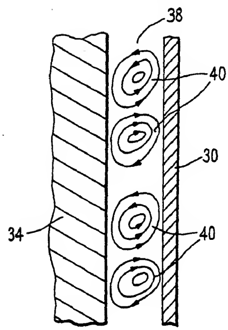
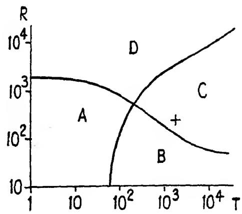


FIG. 3



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pH Controller

This invention relates to an apparatus for controlling the pH of a liquid stream.

In treating effluent from a nuclear fuel reprocessing plant it is known to add controlled amounts of an alkali, such as sodium hydroxide solution, continuously to an acidic liquid stream, containing inter alia nitric acid and ferric nitrate, in order to achieve a pH of for example between 9 and 10.5 at which ferric hydroxide floc precipitates out, and so to trap much of the radioactivity present in the stream. This process involves mixing the added alkali with the acidic liquid in a tank within which is a mixing impeller, and using a pH electrode to monitor the pH of the liquid leaving the tank. However such a mixing technique is detrimental to the flocculation process because of the high shear generated by the mixing impeller, and is found to take up to half an hour to reach a steady state if the input stream is changed, because the residence time in the tank is typically a few minutes and because the output pH fluctuates significantly due to by-passing and inadequate mixing.

According to the present invention there is provided an apparatus for controlling the pH of a liquid stream, comprising a mixing chamber of annular shape defined between an outer member defining a stationary cylindrical outer wall of the chamber, and an inner cylindrical member coaxially and rotatably arranged within the outer member, the mixing chamber having at one end thereof an inlet duct for the liquid stream, and at the other end thereof an outlet duct for the liquid stream, means for rotating the inner member, means for adding a pH-changing additive to the liquid stream, means for monitoring the pH of the liquid stream in the outlet duct, and means for adjusting

the additive adding means in accordance with the monitored value of pH so as to maintain the pH within a desired range.

The apparatus of the invention provides much more rapid and thorough mixing than does the aforementioned mixing tank, so enabling the pH to be controlled more steadily, and also subjects the liquid to much less shear which improves the flocculation process. Within a liquid-filled annular mixing chamber with the inner wall rotating the liquid flow is characterized by the existance of toroidal pairs of vortices rotating in opposite directions. This type of vortex is known as a Taylor vortex. Where the liquid also undergoes axial flow the nature of the flow depends upon the flow rate, and can be characterised by the Reynolds number and the Taylor number, as discussed later. The different flow regimes are summarized by J.W. Polkowski in "Turbulent Flow between Coaxial Cylinders with the Inner Cylinder Rotating" (Trans. of the ASME, Vol. 106, 1984, p 128). J. Legrand et al. in "Circumferential Mixing in One-Phase and Two-Phase Taylor Vortex Flows" (Chem. Eng. Science Vo. 41, No. 1, pp 47-53, 1986) indicate that in laminar flow with Taylor vortices there is very little intermixing between successive pairs of vortices along the flow direction, and that circumferential mixing within any one vortex pair is very weak. However it has now been discovered that very effective mixing can be achieved by a suitable choice of the flow regime.

Preferably the flow rate and the dimensions of the annulus are such that the Reynolds number lies between about 200 and 400, and preferably the rotation rate is such that the Taylor number lies between about 1000 and 6000. For lower Taylor numbers the mixing is less effective, while for higher Taylor numbers there is excessive shear.

The invention will now be further described, by way of example only, and with reference to the accompanying drawings in which:

Figure 1 shows a pH control apparatus, with a mixing chamber shown in longitudinal sectional view, and other components shown diagrammatically;

Figure 2 shows a diagrammatic sectional view of part of the mixing chamber of Figure 1, to a larger scale, showing the flow directions in the vortices; and

Figure 3 shows a parametric graph of different flow regimes.

Referring to Figure 1 there is shown a pH control apparatus 10 for a nuclear fuel reprocessing plant, with an inlet duct 12 for an effluent stream consisting principally of 0.5 molar nitric acid with ferric nitrate (pH = 0.3), a mixing chamber 14, in which 7 molar sodium hydroxide is added to the effluent, and an outlet duct 16 for the resultant mixture. In this case it is desired to achieve a pH in the outlet stream of between 2 and 3. The pH of the liquid at the upper end of the mixing chamber 14 is measured by a pH electrode 18, connected to a microprocessor 20, signals from which control operation of a metering pump 22 which pumps the sodium hydroxide solution from a storage tank 24 to the mixing chamber 14 via a duct 26.

The mixing chamber 14 comprises an upright outer cylindrical casing 30 closed at its lower end 31, of internal diameter 70 mm, to which the ducts 12, 26 and 16 communicate. A bearing 32 is provided at the centre of the lower end 31 of the casing 30. Coaxially arranged within the casing 30 is a cylindrical rotor 34 of external diameter 60 mm and of length 385 mm, at the lower end of

which is a central boss 35 which locates in the bearing 32. A shaft 36 extends coaxially from the upper end of the rotor 34, connected to a motor (not shown) whereby the rotor 34 is rotated during operation. There is thus defined an annular flow chamber 38 between the rotor 34 and the casing 30, of volume about 0.4 litres.

In operation the effluent stream is supplied to the inlet duct 12 at a rate of 100 litres/hour, and the rotor 34 is rotated at a steady speed between 200 and 1000 r.p.m. (revolutions per minute), preferably between 200 and 300 r.p.m. Within the flow chamber 38 the liquid flow defines pairs of vortices 40 (as shown in Figure 2); it has been observed that these vortex pairs together define a single helical path along the chamber 38, Figure 2 showing the flow pattern in two successive turns of the helix. There are about twenty four turns of the helix in the length of the chamber 38, so the length of the helical path is over 4 metres. The residence time for the liquid within the mixing chamber 14 is about 20 seconds, but in this time the added sodium hydroxide becomes very thoroughly and uniformly mixed with the effluent stream, so the pH of the outlet stream is steady.

It will be appreciated that the pH of the effluent stream may differ from that stated above, and the desired pH of the outlet stream may also differ. For example the effluent stream might contain 0.2 molar nitric acid (pH 0.7), and also 2.5 M sodium nitrate and 400 mg/litre of ferric iron as ferric nitrate, and with this stream the control apparatus 10 was found to maintain the outlet stream at a desired pH of 9 with fluctuations of no more than plus or minus 0.7; if the outlet stream was collected in a tank (not shown), the fluctuations of pH were reduced to 0.2. At this pH the titration graph is much steeper than at pH 2. The rotation speed of the rotor is not

critical as long as it exceeds about 150 r.p.m. below which the mixing is less effective. With a rotor speed of 220 r.p.m. a large degree of flocculation occurs during passage through the flow chamber 38, with ferric hydroxide floc particles up to 5 mm size emerging in the outlet stream.

The flow regime may be characterized by the axial Reynolds number R, and the Taylor number T. These are defined by:

$$R = 2b\,V / v$$

and $$T = (w\,r\,b/v)\,(b/r)^{\frac{1}{2}}$$

where: b is the radial width of the annular chamber 38,
V is the mean fluid flow velocity axially through the chamber 38,
w is the angular velocity of the inner cylinder 34,
r is the radius of the inner cylinder 34
and v is the kinematic viscosity of the liquid.

With the apparatus 10 described above, a flow rate of 100 litre/hour, and a rotation speed of 250 r.p.m., the values of these parameters (taking the value of v as $1.0 \times 10^{-6}\ m^2s^{-1}$, the value for water at 20°C) are:

$R = 272$ and $T = 1600$

(and as the rotation speed is varied between 150 and 1000 r.p.m., the value of T varies between 960 and 6410). The above values are plotted on the parametric graph shown in Figure 3, indicated by the +. The graph indicates the values of R and T at which different flow regimes may be expected to occur, the four types of flow being: laminar (A), laminar with Taylor vortices (B), turbulent with vortices (C), and turbulent (D), as summarized in the

previously mentioned article by J.W. Polkowski. It thus appears that the mixing chamber 14 may be operating in the flow regime C where the flow is turbulent with vortices.

However as mentioned above the flow has been observed to involve a helical vortex, rather than the separate toroidal vortices present at lower flow rates. This is similar to the flow regime described by H. A. Snyder in "Experiments on the stability of spiral flow at low axial Reynolds numbers" (Proc. Royal Soc., 1962, A 265, pp 198-214), where a helical flow pattern was observed, at least for Reynolds numbers above 40 up to about 150. It appears therefore that the upper portion of region B in the graph of Figure 3 may in fact be laminar flow with helical vortices. It will be appreciated that if it is desired to change the geometrical dimensions of the mixing chamber 14, the changes should be made in such a way as to provide substantially the same Taylor and Reynolds numbers as those of the apparatus described, and preferably with the same ratio of inner to outer radius.

Claims

1. An apparatus for controlling the pH of a liquid stream, comprising a mixing chamber of annular shape defined between an outer member defining a stationary cylindrical outer wall of the chamber, and an inner cylindrical member coaxially and rotatably arranged within the outer member, the mixing chamber having at one end thereof an inlet duct for the liquid stream, and at the other end thereof an outlet duct for the liquid stream, means for rotating the inner member, means for adding a pH-changing additive to the liquid stream, means for monitoring the pH of the liquid stream in the outlet duct, and means for adjusting the additive adding means in accordance with the monitored value of pH so as to maintain the pH within a desired range.

2. An apparatus as claimed in claim 1 wherein the flow rate and the diameters of the inner and outer members are such that the Reynolds number lies between 200 and 400.

3. An apparatus as claimed in claim 2 wherein the rotation rate is such that the Taylor number lies between about 1000 and 6000.

4. An apparatus for controlling the pH of a liquid stream substantially as hereinbefore described with reference to, and as shown in, Figure 1 of the accompanying drawings.

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